Available online at www.sciencedirect.com

SciVerse ScienceDirect

Energy Procedia 16 (2012) 290 – 295

Energy Procedia

2012 International Conference on Future Energy, Environment, and Materials

Health Risk Assessment of Cadmium Pollution Emergency

Ming Dou[a], Congying Li[a,b, *]

[a]*College of Water Conservancy and Environment, Zhengzhou University, Zhengzhou 450001, China*
[b]*Department of Applied Ecology, University of Lodz, Lodz 90-237, Poland*

Abstract

Taking river network of West River and North River as the research area, one-dimensional heavy metal model was developed, and its parameters are calibrated by the measured data. According to the designed data of cadmium pollution emergency scenario, the cadmium transport and transformation process in river network were simulated by the model. The health risk assessment method was developed to assess the health hazards caused by the pollution emergency. The research revealed that the carcinogenesis risk caused by the pollution emergency in Foshan city is still acceptable in the current situation. The hazard of acute intoxication is much higher than that of chronic carcinogenesis, and the increase of pollution emergency frequency contributes to the augment of carcinogenesis risk. Therefore, water intake and water use actions from the 50km long reach downward the accident place should be forbidden during the accident.

Keywords: risk assessment; pollution emergency; health risk; Foshan city;

1. Introduction

Different from the usual point and nonpoint source pollution, the pollution emergencies own such special characteristics as suddenness, randomness, disastrousness, and hence the water environment system of the surrounding areas and downstream cities can be always influenced fast during short time. According to the statistic of reference [1], from 1993 to 2004, there are totally 21152 environmental pollution emergencies in China, including 374 extraordinarily serious ones and 566 serious ones. The trend of the pollution emergencies is not satisfying. In recent years, more and more local environment management departments develop contingency plans for pollution emergencies as the indispensable

* Corresponding author. Tel.: +86-0371-67767787
E-mail address: dou_ming@163.com.

 doi:10.1016/j.egypro.2012.01.048

measure to safeguard the safety and stability of the society, while mastering rules of pollution emergencies and evaluating quantitatively the damage to human body health are taken as the supplementary means provided by research institution. However, how to assess the health risk from water environmental pollution emergencies still needs more attention and further research, while the health risk assessment approaches have been applied to assess the health risk from common ones. In this paper, such study was conducted in the water supply system and river system in Foshan City in China.

2. The simulation of cadmium pollution emergency scenario

The study was undertaken in West and North River systems in Foshan city. Foshan city, located in central-northern Guangdong province and the hinderland of Pearl River delta, comprises a region of 3848 km^2, home to 5412 thousand people. With excellent natural conditions and location, Foshan city is the representative of Pearl River delta for its fast industrialization and urbanization. The two major water systems in Pearl River delta, West River and North River are important drinking water sources and navigation channels in Foshan city, where the West River mainstream is 69.1 km long, with 11 tributaries, and the North River mainstream is 100.2 km long, with 13 tributaries. By 2008, there have been 52 certified water plants and 37 ones of them take water from West and North River systems, with a total water productivity of 4222.7 m^3/d. Therefore, to demonstrate the pollutant concentration process in each water plant section when a water pollution emergency happens, the paper assumes the emergency situation with the scenario analysis method, and then simulates the processes of pollutant transport and transformation in West and North River systems, using the heavy metal model.

2.1. heavy metal model

The one-dimensional heavy metal transport/transformation model in river systems consist of the Saint-Venant equations (continuity equation and motion equation), for hydrodynamic process, and the basic water quality equation, for the heavy metal transport and transformation process in the water.

Continuity equation
$$\frac{\partial h}{\partial t}+\frac{1}{B}\frac{\partial Q}{\partial x}=\frac{q}{B} \tag{1}$$

Motion equation
$$\frac{\partial Q}{\partial t}+(gA-Bu^2)\frac{\partial h}{\partial x}+2u\frac{\partial Q}{\partial x}=u^2\left.\frac{\partial A}{\partial x}\right|_z-gu\frac{|Q|}{\varsigma^2 R} \tag{2}$$

Water quality equation
$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}=E_x\cdot\frac{\partial^2 C}{\partial x^2}+\frac{[K_b(f_b-1)h+Kf_b u^m-K_w f_\theta u^{-n}]}{h(1+f_\theta)}C \tag{3}$$

where: h is average flow depth (m); Q is discharge (m^3/s); A is cross-section area (m^2); g is acceleration of gravity; B is discharge width of cross-section (m); q is lateral inflow (m^3/s); u is flow velocity (m/s); R is hydraulic radius (m); ς is Chezy coefficient (m/s); C is heavy metal concentration (mg/L); E_x is diffusion coefficient in the x direction; K_b is desorption coefficient (1/s); K is resuspension coefficient; K_w is deposition coefficient; f_θ is heavy metal distribution coefficient between suspended matters and water in equilibrium state, dimensionless; f_b is heavy metal distribution coefficient between bottom sediment and water in equilibrium state, dimensionless; m and n are exponents, $n=2.0$, $m=4$[2].

The heavy metal model is discretized with the implicit difference method, and then solved by pursuit method. During the calculation of this model, the upstream boundary is set in the Feilaixia reservoir in North River and Gaoyao hydrological station in West River, and the downstream boundary is the gauging and tide stations Whampoa, Sanshakou, Nansha, and so on. The calculation period was from 24th

December, 2005, to 19th January, 2006. The parameters of the heavy metal model was calibrated and verified by synchronized hydrodynamic and water quality monitoring data provided by the environmental protection bureau of Foshan city with the accident in North River in 2005.

2.2. Pollution emergency scenario simulation

The pollution emergency scenario is designed with cadmium pollution accident data in North River as reference, but the place is in the cross between Qingyuan city and Foshan city, not in Shaoguan city. The scenario is described as follows: it assumes that a smeltery there discharges accidently 10000 tons industrial wastewater of high cadmium concentration, 100mg/L, for 4 hours. The other hydrodynamic and water quality conditions are same as those when the model was verified. With the heavy metal model under the designed conditions, the cadmium concentration process in each section of West River and North River was simulated, and the calculated results of some sections are showed in Figure 1.

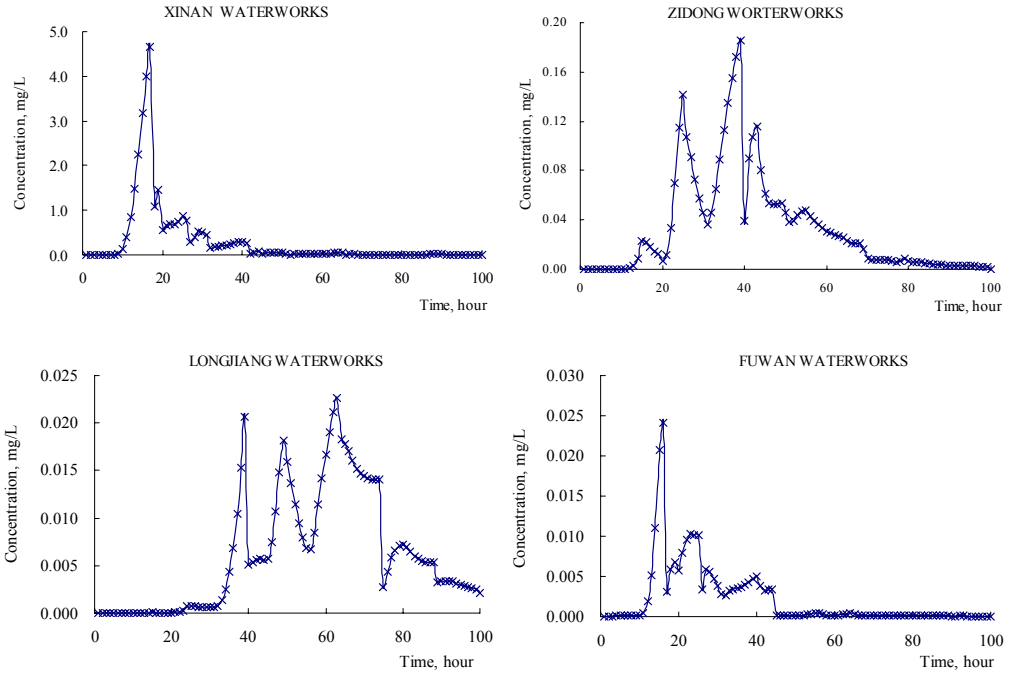

Fig. 1. Simulation result of cadmium pollution emergency in North River

The simulation result showed that cadmium concentration in the waterbody rapidly declined from upstream to downstream. Since the suspended matters and bottom sediment have stronger affinity to cadmium, cadmium can be absorbed to suspended matters through adsorption and then settled in the bottom sediment through deposition, which leads to the rising cadmium concentration in the suspended matters and bottom sediment and the declining dissolved cadmium in the waterbody. Near by the accident spot, the sections of Datang waterworks, Lubao waterworks and Nanbian waterworks located in the North River have higher cadmium concentrations (>10mg/L). When cadmium pollutants move down to the Sixianjiao channel, the junction between West and North River, part of the polluted water from North River upstream flows into West River, leading to that water in West River is polluted and cadmium

concentration rises, and the other part continues to flow down along the North River mainstream. After that, the current in the downstream of river system is reciprocally oscillated with tidal action, resulting in faster cadmium deposition, and the lower flow velocity, the more obvious deposition of heavy metal. Thus, the concentration declines rapidly. By the sections of Yange waterworks, Chencun waterworks in the North River and Fuwan waterworks in the West River, the cadmium concentration peaks have been less than 0.01mg/L, while by the sections of Guizhou waterworks in North River and Xingcuo waterworks in the West River, less than 0.001 mg/L.

3. Health risk assessment

Based on the simulation of cadmium temporal and spatial distribution process during the accident, the health risk assessment to people in Foshan city was conducted.

3.1. Assessment method of health risk

Cadmium is a highly toxic heavy metal, and its hazard to human body has acute toxicity and chronic carcinogenesis, the world-shocked itai-itai disease event because of cadmium intoxication was an example. Entering human body, cadmium will accumulate gradually in kidney and bone, and take place of calcium in the bone, making the bone heavily soften. Besides, cadmium can disturb the enzyme system of human and other organisms, leading to the visceral dysfunction and further cancerization and aberration.

According to the environmental hygiene and toxicology principles, pollution emergency with higher pollutant concentration and shorter duration impacts more heavily on human than continuous pollution discharge process with the equal dose of pollutant and lower concentration and longer duration. Therefore, this paper discusses human health risk caused by cadmium pollution accidents from the two following aspects. On the one hand, the critical toxic dose of cadmium was set to determine whether the accident can lead to acute toxicity. Based on the references [4]-[6], it was determined that the acute oral critical toxic dose of cadmium was 10mg/d. On the other hand, to assess the carcinogenic risk because of the cadmium accumulation in the human body, it assumed that both the hazard effects on human body exposed to the short duration and high dose of hazardous matters and those exposed to the lifetime duration and low dose ones were the same, expressed by lifetime accumulative average daily exposure dose.

The carcinogenic risk on human body posed by cadmium intake was computed by the following health risk assessment model.

$$R_{Cd} = [1 - \exp(-D\eta)] / AGE \qquad (4)$$

where: R_{Cd} (a^{-1}), D(mg/(kg·d)), η ((kg·d)/mg), are respectively average personal carcinogenic risk, average daily exposure dose per body weight unit and oral cadmium carcinogenic coefficient, $\eta = 6.1$; AGE is average human longevity in the research area, $AGE = 70$a.

When pollution accident happens, the index of D can be calculated by the following formula.

$$D = \frac{\sum_{i=1}^{n} (WD \times \overline{C}_i) \times FR}{GD \times ET} \qquad (5)$$

where: $\overline{C}_i$ is average daily cadmium concentration in waterbody during the pollution accident, mg/L; WD is average daily water intake per capita, $WD = 2.2$, L/d; FR is possible occurrence times of pollution accident during the man's lifetime, $FR = AGE / f$; f is accident frequency, years/time; GD is average

weight of people in Foshan city, GD=70, kg; ET is average exposure time, d; n is pollution emergency influence time on waterbody, computed by the heavy metal model, d.

According to the statistic data of the research area, the frequency of the pollution emergency, caused by industrial effluent in Foshan city, was 20 years/time. Besides, the accident frequencies of 1 years/time and 100 years/time were chosen for the comparison of them.

3.2. Result Analysis

According to the cadmium concentration process of each waterworks section simulated by the heavy metal model, the maximum daily cadmium intake per capita was calculated, and then the distinguish whether it could lead to poisoning with the critical toxic dose of cadmium. Meantime, the index of D, average daily exposure dose, under each different accident frequency, was calculated by formula 5. The carcinogenic risk R_{Cd} of the people whose water is supplied by the 37 waterworks in Foshan city was assessed by formula 4, and then the annual cancer number P_{Cd}, was calculated through the value of R_{Cd} being multiplied by the respective population in the water supply area of each water plant. The assessment results of some waterworks influenced remarkably by the accident are showed as the table 1.

Table 1 The results of health risk assessment under different pollution emergency frequencies

Frequency	100 years/time		20 years/time		1 years/time		Maximum daily oral intake/ mg/d	Whether having acute intoxication
Waterworks	R_{Cd}/ a^{-1}	P_{Cd}/capita	R_{Cd}/ a^{-1}	P_{Cd}/capita	R_{Cd}/ a^{-1}	P_{Cd}/capita		
Datang	3.54×10^{-6}	0.11	1.24×10^{-5}	0.39	2.46×10^{-4}	7.69	52.25	Yes
Lubao	1.74×10^{-6}	0.08	6.09×10^{-6}	0.27	1.21×10^{-4}	5.44	19.17	Yes
Nanbian	1.51×10^{-6}	0.04	5.29×10^{-6}	0.13	1.05×10^{-4}	2.64	25.88	Yes
Shitang, Xinan, Jianlibao	1.32×10^{-7}	0.04	4.62×10^{-7}	0.15	9.23×10^{-6}	3.08	2.06	No
Xiaotang, Nanhai	2.74×10^{-8}	0.01	9.60×10^{-8}	0.05	1.92×10^{-6}	1.02	0.33	No
Shakou	1.24×10^{-8}	0.00	4.34×10^{-8}	0.02	8.69×10^{-7}	0.33	0.14	No
…	…	…	…	…	…	…	…	…
Sum		0.30		1.06		21.12		

According to the acceptable individual annual carcinogenic risk level of the drinking water source, made by the International Commission on Radiological Protection (ICRP), USA Environmental Protection Agency, Netherland Ministry of Construction and Environment and other international organizations, the maximum value of it in Foshan city, R_{Max}, is given as 1.0×10^{-5} a^{-1}. Combining with the assessment results in table 2, the health risk caused by the cadmium pollution emergency in Foshan was quantitatively analyzed, and some conclusions were drawn as follows:

- In the current situation, the carcinogenic risk caused by the cadmium pollution emergency in Foshan city is still acceptable. At the accident frequency of 20 years/time, similar to the current situation, there is only Datang waterworks where the value of R_{Cd} is larger than that of R_{Max}, Lubao and Nanbian waterworks where the value of R_{Cd} is approximate to that of R_{Max}, and the other waterworks where the value of R_{Cd} is less than that of R_{Max}, which can't form threat on the long-term human health. Since the preceding three waterworks are located in the upstream of North River, which are far away from the urban area of Foshan city and has a few people to supply water, there are total 1.06 cancer cases annually caused by pollution emergency in Foshan city.
- The risk of acute toxicity on human body caused by the accident is further larger than that of chronic carcinogenesis. The simulation result showed that, during the accident, the cadmium concentration in the

river segment upward Nanbian waterworks, about 40 km long, seriously exceeded the normal standard of the supplied drinking water, 0.001mg/L. Especially, in the three sections of Datang, Lubao and Nanbian waterworks, it was 23.8mg/L, 8.7mg/L and 11.8mg/L respectively, and if supplying water continually during the accident, the maximum daily oral cadmium intake of the residents in the water-supply area would be 52.25mg/d, 19.17mg/d and 25.88mg/d respectively, exceeding the oral critical toxic dose of cadmium, 10mg/d. Therefore in this situation, it must lead to the poisoning accidents of the residents.

- The increase of pollution emergency frequency contributed to the augment of carcinogenic risk to human body. When the frequency is 100 years/time, the value of R_{Cd} is less than that of R_{Max} in the water-supply area of each waterworks, and there are total 0.30 people suffering from the cancer annually, which demonstrates that at very low frequency the chronic carcinogenic risk to human body is unobvious. When the frequency is 1 year/time, the carcinogenic risk in each water supply area of Datang, Lubao and Nanbian waterworks rises sharply, the value of R_{Cd} exceeds 1.0×10^{-4} a^{-1}, and as to the seven waterworks from Shitang to Zidong, the value of R_{Cd} is less than that of $R_{Max,}$, but exceeds 1.0×10^{-6} a^{-1}, and the annual total cancer cases in the city reach to 21.12 capita/year. Therefore, if the cadmium pollution emergency frequency is excessively high, the annual carcinogenic risk will increase significantly.
- Since the accident place was set outside Foshan city, the main risk affected area was in the upstream from Datang waterworks to Nanbian waterworks, and the risk to the city was less relatively. However, once the accident happens inside the city, the consequence will be much worse. According to the research, if a cadmium pollution accident of the same level happens in the future, it will need no less than 40~50km long reach to reduce the cadmium concentration in the water body to a lower level. Hence, that taking water from the area within 50km ranges downward the accident place should be prohibited.

4. Conclusion

With the further socioeconomic development of Foshan city in China, there will be more inducing factors of pollution emergency, which leads to the increase of human health risk. Therefore, great efforts have to be made to prevent and control the water pollution, where that building water environment simulation & early warning system and then making health risk assessment is an important measure. In this paper, through the combination of multiple methods such as the one-dimensional heavy metal model for heavy metal transport and transformation in the river network, health risk assessment theory and scenario analysis, the health risk assessment of the cadmium pollution emergency in the North River is implemented, which can significantly improve the conservation work of the drinking water sources.

References

[1] Pan Hongbo, Wang Mei, Gao Yu. Developing environmental risk assessment to prevent sporadic pollution accidents. *Environmental protection science* 2006, 32(4): 63-65

[2] Ye Shouze, Xia Jun, Guo Shenglian, Chen Xiaohong. Simulation prediction and assessment of water environment in reservoir. Peking: China WaterPower Press, 1997

[3] Dou Ming, Li Xiaohua, Xie Ping. Pollution emergency plans for drinking water source in Foshan City. Project report of Environmental Protection Agency in Foshan City. 2006

[4] Qin Junfa, Li Zengxi. The Effect of cadmium on human health. *Guangdong Trace Elements Science* 2004, 11(6): 1-10

[5] Wu Hongchi, Yangqian, Yu Haitao, ect. Empirieal study of single large dose of cadmium-Induced acute renal injury. *Chinese Journal of Trauma and Disability Medicine* 2007,15(6): 1-3

[6] Yao Zhiqi. Cadmium dosage of itai-itai disease patient in Supernatural River- reaction relationship. Foreign Medical Sciences: Section of Hygiene, 1980, 6: 327-331